Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Laser pulse shaping for multi-bunches photoinjectors

Q1 F. Villa [a,*], S. Cialdi [b], M.P. Anania [a], G. Gatti [a], F. Giorgianni [c], R. Pompili [d]

[a] Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, via E. Fermi 40, 00044 Frascati, RM, Italy
[b] Università degli Studi di Milano and INFN-Milano, via G. Celoria 16, 20133 Milano, Italy
[c] Università La Sapienza di Roma, Via A. Scarpa 14, Roma, Italy
[d] INFN-Roma Tor Vergata and Università di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy

ARTICLE INFO

Keywords:
Photoinjectors
Pulse shaping
Multi-bunch

ABSTRACT

Multi-bunch electron linac operation is required in many applications, like plasma wake field acceleration, narrow band THz generation and two color FEL. We present a short review of laser techniques employed in multi-bunch photoinjectors and propose a new scheme based on spectral phase manipulation of the laser pulse. In conclusion we show some application of multi-bunches electron beams done at SPARC_ LAB.

1. Introduction

Electron pulse trains of some hundreds pC charge and sub-ps length can be useful to drive pump-probe experiments, efficient generation of THz radiation and plasma accelerators.

Two color FEL are best suited to perform pump-probe experiments [1], especially in the x-ray wavelengths, due to their tunability. The two color can be achieved using undulators with different characteristics [2], but can also be realized using two electron bunches at different energy inside an undulator [3]. These lasers can also produce attosecond pulses using the coherence and the large spectral band of those systems [4].

THz radiation can be produced in Coherent Diffraction/Transition Radiation [5], when an electron bunch comes near/though surfaces with different dielectric constants. Near monochromatic THz sources use train of electron pulses [6] to reduce the spectral width of the radiation.

Wake Field Acceleration is used as a new technique to achieve high accelerating field ($>$ 1 GV/m) instead of more conventional RF cavity. Wakefields can be excited in plasma using intense laser pulses or a train of electron bunches. In the latter case, called resonant Plasma Wake Field Acceleration (PWFA) multi-bunch operation is mandatory, due to the fact that the wake is generated by electron bunches (one or more) called drivers followed by a smaller bunch at an odd number of half plasma lengths from the driver, where the accelerating fields have maximum [7].

2. Comb laser systems

Different methods to obtain a train of electron bunches separated by few ps were proposed and tested. While it is possible to start with a single electron bunch at the cathode and make an electron comb after the acceleration [2], it is more efficient to have the electron comb directly at the start of the linac, shaping the photocathode laser pulses accordingly.

A simple technique to obtain a ps-train of laser pulses uses the birefringence properties of crystals [8]. Those crystals have two different diffraction indexes depending on the orientation of the laser polarization to the crystal optical axis. Choosing the laser polarization it is possible to balance the intensity that propagate along the fast axis of the crystal in respect of the part that propagate along the slow axis of the crystal (Fig. 1). The transverse shape of the pulses remain the same, while the longitudinal separation depends linearly on the crystal length and on the diffraction indexes difference. It is possible to have more crystals of different length in series, separated by a half wave plate to tune the pulses polarization, in order to obtain more pulses. Usually, αBBO crystals are used, because they have a good transmission and strong birefringence in the UV spectral region. This scheme is very simple (no critical alignments) and robust, with an high overall transmission, but the pulses are produced only as a power of two and the separation along the pulses is symmetric to the center of the train. The delay between pulses can be changed only using different crystals, allowing discrete tuning only.

Another system to obtain a train of pulses is to manipulate the spectral content using Fourier optic. Such a system can be composed by a diffraction grating, a lens at its focal distance from the grating, a second lens at two focal distance, a second grating at a focal distance and a mirror (and is named 4*f* from the focal lengths between the two gratings, as in Fig. 2). At the middle of the system the laser spectral content is mapped on the transverse dimension. In this point an intensity or phase mask can be inserted to impose the chosen spectral shape, that is Fourier transformed in the longitudinal (time) dimension of the pulse at the exit of the system [9]. This system can use a Dazzler [10], which performs the shaping of the input pulse into a similar rectangular pulse in the frequency

Q2 * Corresponding author. Tel.: +39 0694038355.
E-mail addresses: fabio.villa@lnf.infn.it, il.fabio.villa@gmail.com (F. Villa).

0168-9002/$ - see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.nima.2013.11.060

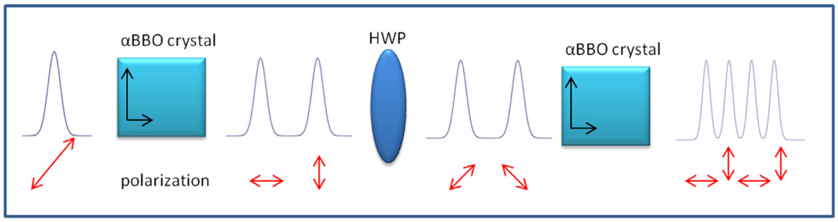

Fig. 1. Birefringent crystals laser comb scheme; HWP: half wave plate.

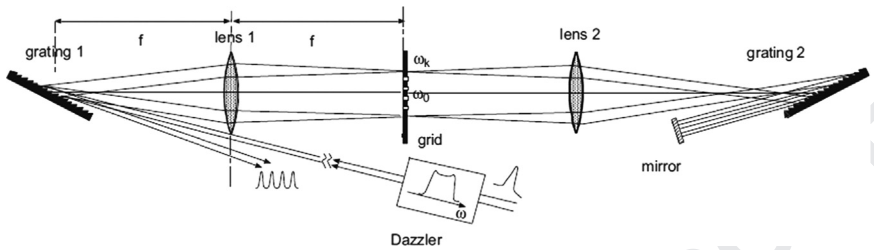

Fig. 2. 4-*f* scheme with transmission mask.

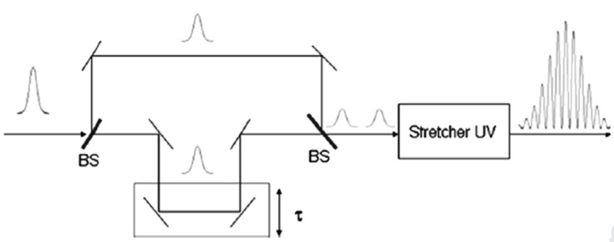

Fig. 3. Comb generation scheme with interference of two pulses.

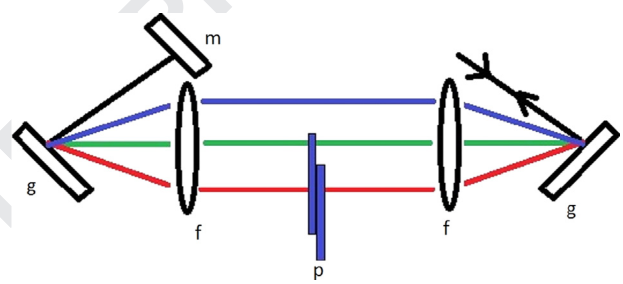

Fig. 4. 4*f* system for the generation of 3 pulses with thin plates. g=grating, f=lens, p=plate, and m=mirror.

domain, and a 4*f* system in the asymmetric (stretcher) configuration with a spatial mask at the Fourier plane. A liquid crystal phase mask can lower the losses of an intensity transmission mask, paying the price of a more complex and costly system, because the liquid crystal cells of the mask must have low losses in the UV spectrum. This system can impose tunable delay changing the mask, but at price of a low transmission due to the diffraction efficiency of the gratings and the losses imposed by the mask.

In order to produce narrowband THz radiation can be useful to have many electron bunches separated by few ps (the inverse of the THz frequency) [11]. A suitable photochathode laser configuration can be achieved by interference. A single laser pulse can be stretched (with a linear chirp proportional to $\exp(ibt^2)$) and sent to an interferometer (such as Michelson–Morley) where a part of the pulse is delayed by a quantity τ by having one arm of the interferometer longer than the other (Fig. 3). When the pulses are superimposed, the resulting intensity is

$$I(t,\tau) = I(t) + I(t+\tau) + 2\sqrt{I(t)I(t+\tau)}\,\cos(\omega\tau + b\tau^2 + 2bt\tau) \quad (1)$$

thus having a beating frequency of $2b\tau$. Tuning the chirp parameter b and the delay τ it is possible to have a sinusoidal modulation of the intensity profile at the desired frequency, corresponding to the pulse repetition rate useful for narrowband THz generation. This configuration was tested at Brookhaven National Laboratory [6]. Its advantages are the tunability of the beating frequency, thus of the repetition of the beam, and the possibility to have large number of bunches in the train, but the envelope of the train will follow the shape of the single pulse, in general a gaussian shape, thus the pulses will not have the same peak intensity throughout the train, and the losses of the scheme may be high due to the stretcher losses.

A variation of this scheme has a polarizing beam splitter in the interferometer and a quarter wave plates in each arm [12]: in this case the interference is suppressed, because of the orthogonal polarization of the pulses at the recombination point, and the peak intensity of the two pulses is set by the polarization of the laser at the entrance of the beam splitter. This scheme has very good online delay tunability, but its cost and required space increase rapidly if the system is replicated to have more than two pulses.

3. New comb system

We propose a new scheme aimed to obtain a train of laser pulses based on phase shift of different spectral components of the photocathode laser pulse: thin (few tenths of mm) fused silica plates placed in the Fourier plane of a symmetric 4*f* system (Fig. 4) impose a phase shift of different spectral components, that correspond to a delay in time domain. By tuning the thickness of the plates it is possible to choose independently the delay of each pulse and by tuning the position in the transverse plane it is possible to choose the energy of each pulse. This method is also useful for generation of an odd number of pulses with different delay between them, i.e. in the case of PWFA experiments.

Using a single, thick (few mm) plate and the 4*f* system in stretcher configuration (Fig. 5) it is possible to have a sinusoidal modulation that can be tuned with the stretching parameter (proportional to the displacement h from the symmetric configuration of the 4*f* system) similar to what is produced in the interferometric scheme. It is possible to cut the tails of the pulse train, in order to have a more uniform peak intensity throughout the pulses, by inserting a slit in the Fourier plane.

The main advantage of the system, compared to the previous, is its flexibility to change from one to few to many bunches with

Please cite this article as: F. Villa, et al., Nuclear Instruments & Methods in Physics Research A (2013), http://dx.doi.org/10.1016/j.nima.2013.11.060